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Using Nitrogen Efficiently

Life After Frost

Liability & the Lawn Care Industry

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BETTER TURF THROUGH RESEARCH AND EDUCATION

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The Massachusetts Turf and Lawn Grass Council Incorporated is chartered under the laws of the Commonwealth of Massachusetts as a non-profit corporation. The turf council seeks to foster "Better turf through research and education."

More detailed information on the subjects discussed here can be found in bulletins and circulars or may be had through correspondence with the editor.

The Editor wishes to thank Loretta J. Cassel for her research and technical assistance in the construction of this bulletin.

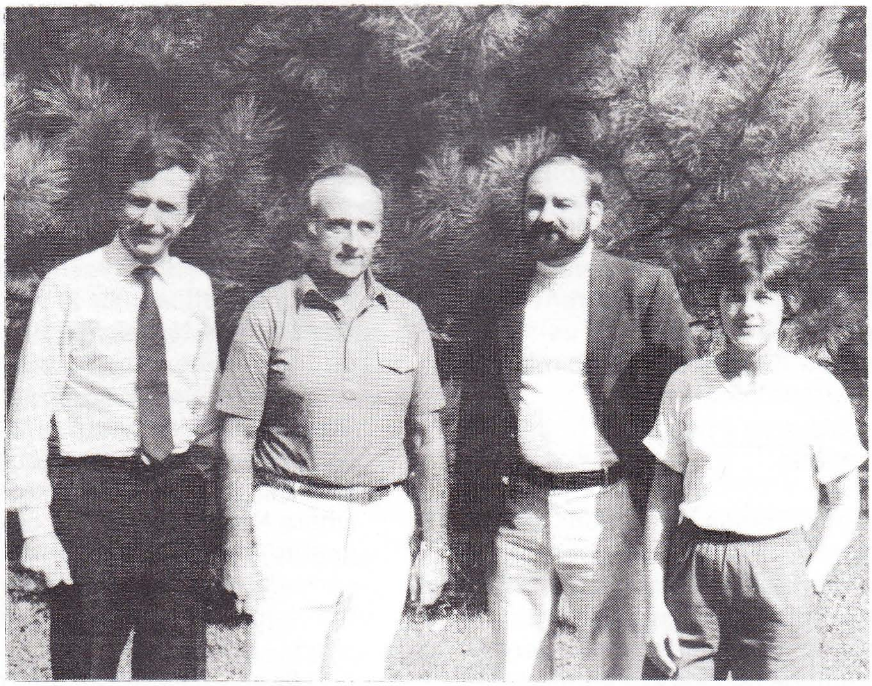
TURF CLIPPINGS

GCSAA AWARDS GRANT

James Prusa, Director of Research and Education for the GCSAA, recently awarded the University of Massachusetts Turf Tissue Culture Program a grant for $60,000. This grant will aid in the research and development of the program. The goal of the program is the development of improved turf species through the use of tissue culture techniques.

TURF FIELD DAY, 1982

Turf Field Day at the University of Massachusetts Turf Research Station in South Deerfield was highly successful this year. 250 people from throughout the Northeast attended on June 23 for a tour of the station and an explanation of the type of research being conducted there. The tour was followed by lunch at the top of Mt. Sugarloaf.



(Left to right): James Prusa, GCSAA: Dr. Joseph Troll; Dr. William Torello; Cynthia Lincoln, Professor, Asst. Professor, and Research Assistant; respectively, for the Department of Plant and Soil Science.

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Using Nitrogen Efficiently - Theoretical Aspects

By Roland D. Hauck
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Almost without exception, those concerned with the use of N fertilizers agree that they should be used efficiently. But what does N fertilizer use efficiency mean? Depending on whether one is concern ed mostly with obtaining maximum yields or profits, or mainly with srtiving for minimal environmental stress, "N fertilizer efficiency" may have any one of several meanings. It can be defined in terms of plant uptake of N, crop yield, crop quality, or economics.

A responsible viewpoint of N fertilizer efficiency considers yields, profits, and long-term environmental concerns. This paper discusses several definitions of N fertilizer efficiency from different viewpoints, and discusses also the problem of using fertilizer N for maximum profit consistent with minimal adverse effects on environmental quality.

Definitions and Viewpoints

Probably the most common definitions of fertilizer efficiency are based on plant uptake of nutrient, expressed either as the amount of fertilizer-derived nutrient in the entire plant (or in a particular part of the plant), or as the percentage recovery of applied nutrient. Percentage recovery of applied N is a calculated value relating the amount of N in the plant obtained from fertilizer to the amount of fertilizer N applied. Usually, this term is used in relation to uptake of N by the entire above-ground parts of the plant, but sometimes refers only to the N recovered in the harvestable parts of the plant.

Although definitions of N fertilizer efficiency based on plant uptake of N can be stated clearly, their meanings may be different depending on one's interpretation of the term "efficiency." For example, consider N fertilizers A and B applied at equal rates to soil. From one point of view, fertilizer A can be said to be more efficient than fertilizer B if more N from A than from B is found in the plant. On the other hand, suppose that crop yields (e.g., total dry matter or grain) from A and B are the same. Even though a smaller amount of N is taken up by plants from B than from A, the N from B is used more efficiently by the plants; that is, less N is needed from B to produce the same yield as from A. From this viewpoint, fertilizer B would be considered more efficient than fertilizer A. Note that in this example, the term "efficiency" was used in two contexts, one implying efficiency as an inherent property of fertilizers, the other implying efficiency of plant use of fertilizer. This point will be brought up again later.

Nitrogen fertilizer efficiency can be defined in terms of the yield of crop which is obtained for successive increments of N applied. Thus, under most agricultural situations, each additional increment of N produces less increase in yield and, therefore, each successive increment can be considered increasingly less efficient. Or, from a plant physiological point of view, efficiency can be defined in terms of the yield obtained from each increment of N which is taken up by the plant; that is, efficiency is defined not in terms of the N applied, but in terms of the N which is taken up by the plant and used to produce harvestable crops.

The agricultural economist usually views fertilizer N efficiency in terms of the cash value of product in relation to cost of the N applied; that is, in terms of profit per increment of applied N. Except where N content affects crop quality and where crop quality has marketable value, the economist is concerned not with the amount of N in the plant, but in the yield of commodity in relation to the cost of N applied.

Each definition of N fertilizer efficiency, whether it is based on N uptake, crop yield, crop quality, or economics may have one or more variations. N uptake or use may be expressed on a cumulative or incremental basis; that is, in terms of the total fertilizer N in the crop in relation to the total N applied or in terms of the proportion of total N in the plant that is taken up for each increment of N applied, respectively. As mentioned earlier, definitions of efficiency can be based on the N content or yield of the entire plant, on the above-ground portions of the plant, or on a specific portion of the above-ground or below-ground parts, such as the harvestable portion.

Faced with a bewildering array of definitions for N fertilizer efficiency, how does the nonspecialist in soil fertility choose among definitions and understand their meanings?

One must first understand the purpose for which a particular measurement of fertilizer efficiency is made. For example, it may be that the purpose is to identify the rate of N application which minimizes the amount of N that escapes from the soil-plant system to the surrounding environment, or, stated in another way, to achieve maximum recovery of applied N during the cropping season. As discussed more fully elsewhere (12), highest yields usually are not obtained with N application rates which maximize either total recovery or percentage recovery of applied N. Where N application rates are excessively high, recovery of N may be high, but the plant absorbs N in excess of its needs or at a time when the plant cannot metabolize the N in a productive manner. That is, the plant takes up N that it does not need. Maximum percentage recovery of applied N usually occurs at the lower rates of N application and, consequently, usually at lower yield levels.

Using data for coastal bermudagrass and wheat, Tucker and Hauck (12) calculated N fertilizer efficiency on the basis of several definitions. The data clearly show that the rate of applied N considered most "efficient" depended upon one's viewpoint. For example, on the basis of percentage recovery of applied N, maximum N fertilizer efficiency on bermudagrass was obtained at an application rate of 224 Kg N/ha.

From a plant physiological viewpoint, a greater percentage of the applied N was used in dry matter production at the 112 kg N/ha rate, even though total dry matter production was low.

The economist might judge the application rate of 1,120 kg N/ha to be the most efficient because it resulted in the greatest profit, even though a considerable amount of applied N was not taken up by the crop.

Those concerned mainly with the amount of fertilizer N left residual in the soil in leachable form (i.e., a conservationist viewpoint) might consider the 112 kg N/ha rate the most efficient because at this rate less fertilizer N remained in the soil after cropping, even though a greater percentage of applied N was removed by the plant at the 224 kg N/ha rate.

The conservationist and plant physiological viewpoints of efficiency, if used in making fertilizer recommendations, would conserve N but result in a dollar return for fertilizer less than one-fourth of that which would be obtained from the application rate judged most efficient from an economic viewpoint. However, the economically efficient N application rate was highly wasteful of N and left considerable N in leachable form in the soil.

Short-Term Versus Long-Term Efficiency

Seldom is the efficiency of an N fertilizer considered beyond the season of application. A long-term viewpoint of efficiency considers also the residual value of the fertilizer—that is, the amount of fertilizer that remains in the soil after the first growing season and is taken up in subsequent croppings. Commonly, 20% to 40% of applied N remains in the soil after the season of application, either as inorganic N or N that has been assimilated into the soil organic matter. Some of the assimilated (im-

mobilized) N is remineralized and taken up by plants, thereby adding to the overall efficiency of the N fertilizer.

Accurate measurement of the residual value or overall efficiency of an N fertilizer requires expensive studies conducted for several years using tracer techniques. Such studies at present are of concern more to those interested in the total environmental impact of N fertilizer use than to those concerned mainly with the crop production value of fertilizers. Currently, information is lacking on the differences in residual value among soluble N fertilizers, although some information is available on the residual value of slow-release N materials. Long-term viewpoints of N fertilizer efficiency will increase in importance as appreciable amounts of residual fertilizer N accumulate in intensive crop management systems.

Fertilizer Efficiency Versus Management Efficiency

Many factors affect N fertilizer efficiency: N source and application rate, method and time of application, plant species and their N uptake and use patterns, cropping history of soil receiving fertilizer, nature and extent of chemical and microbiological reactions to which the fertilizer is subjected, other soil characteristics and management practices, and climate. The influence of these factors on N fertilizer efficiency is reviewed in articles by Olson *et al.* (7), Parr (8), Stanford (9), Ingestad (4), Vitosh *et al.* (13), Terman (10), and Thomas (11). Obviously, the term "N fertilizer efficiency" usually does not refer to the efficiency of the fertilizer *per se*, but to the efficiency with which the fertilizer is used. When studying the action of different N fertilizers, one may be justified in comparing their relative efficiencies under comparable soil, fertilizer, and crop management conditions. But one cannot measure the efficiency of a single N fertilizer without reference to the factors which determine its efficiency.

The efficiency of a single N fertilizer cannot be stated in absolute terms; the fertilizer's relative efficiency depends on its inherent properties as they are influenced by the fertilizer management system. For example, the chemical properties of urea are such that when urea is applied to soil, rapid enzymatic hydrolysis usually occurs, resulting in a micro-zone high in pH and ammonium ion concentration. If the urea is permitted to hydrolyze on the soil surface, ammonia may be volatilized from the microsite. The degree of ammonia volatilization depends on soil properties, environmental conditions, and management practices. No ammonia is volatilized to the atmosphere if urea is incorporated into the soil. Therefore, when evaluating urea or other materials as sources of N, it is not the efficiency of the fertilizer *per se* that is being measured, but the efficiency of the fertilizer management system.

Efficient Use of N

A prescription for effective use of N fertilizer aims for the highest yields which are possible consistent with fertilizer supply, profit, and environmental concerns. Highest possible yields, profits, and recoveries of applied N all cannot be obtained with this prescription, but it offers a reasonable compromise between costs and benefits over a succession of cropping seasons.

In general, two approaches are taken to increase the effectiveness of fertilizer N use: (1) minimizing loss of plant-available froms of N from the plant root system, and (2) manipulating crop and fertilizer management systems in such a way as to permit the plant to approach its genetic capability for maximum yield and quality. Martin *et al.* (5) and Olson (6) summarized some of the many ways in which fertilizer N use efficiency can be increased by manipulating soil, crop, water, and fertilizer management practices; e.g., by applying fertilizer N to the growing plant, by maintaining cover crops, and by growing deep-rooted plants that have the ability to scavenge subsoils for nitrate N. Methods directed mainly toward reducing fertilizer N loss have been discussed by Hauck and Bremner (2, 3). They include: control of nitrification through use of nitrification inhibitors and slow-release N fertilizers, control of ammonia volatilization of surface-applied urea through use of urease inhibitors or amendments to urea which alter the chemistry of the urea-soil microsite, and control of the form of N (e.g., ammonium versus nitrate) which is presented to the plant through use of nitrification inhibitors. The need for more efficient use of soil N and residual fertilizer N is emphasized in articles by Parr (8) and Stanford (9).

A detailed discussion of these various means of increasing N fertilizer use efficiency under various crop management systems is not intended here. Rather the discussion will focus on the information needed to formulate a prescription for increasing crop yields while decreasing the potential adverse effects on the environment which can result from intensive N fertilizer use.

Sources of Information

Most farmers have available empirical information from field plot research conducted at agricultural experiment stations, and also some general information about the agronomic properties of and economic factors governing the use of N fertilizers. Farmers may have available the results of crop yield tests made on their own or neighboring farms, or are at least knowledgeable about the usual soil, fertilizer, and crop managment practices in their locality. Judicious use of the above information probably will result in profitable yields but may not result in maximum efficiency of N fertilizer use as defined in terms of maximum profit with minimum waste of N. Needed to formulate a prescription for optimum use of fertilizer N is quantitative information on plant composition and soil-fertilizer interactions.

Basic Information Needs

Stanford (9) lists four kinds of basic information needed for predicting optimum use of soil and fertilizer N: (1) the total amount of N in the crop at the expected yield level (the internal plant requirement for N), (2) the amount of soil N which is made available to the plant during the growing season, (3) the amount of residual mineral N in the root feeding zone early in the growing season, and (4) the expected recovery of the plant-available forms of N, ammonium and nitrate. Needed also is a detailed knowledge of N fertilizer transformations in soil.

The plant requirement for N is obtained by measuring the average percentage of N in the main plant parts (e.g., grain, leaves, stalks, or roots) at the maximum level of attainable yield. The sum of the products of total dry matter production times percentage N for each plant component gives the total N content of the plant. For example, Stanford (9), from a survey of sugarcane yields, concluded that maximum production of cane sugar invariably was associated with an N concentration of 0.2% in the total dry matter (leaves and cane), corresponding to 1 kg of N/metric ton of millable cane. Studies of data for corn indicate that maximum grain yields usually are associated with an N concentration in total dry matter of about 1.2% (1.16% to 1.25%), regardless of the level of attainable yield and over a wide range of management conditions. Assuming that the average dry weight of corn grain is 50.5 ± 4% of the total dry matter weight, 134 ± 11 kg N/ha (120 + 10 lb N/acre(would need to be taken up by the plants to produce 100 bushels of corn, corresponding to an internal N requirement of 0.55 kg or 1.2 lb N/bushel. Similar information is available to some extent for grain sorghum, wheat, and other small grains.

The second piece of basic information needed in order to predict optimum use of N is the amount of N from soil organic matter which is made available to the plant. Various methods have been developed to estimate the amount of N which is expected to mineralize during the growing season. Most of the methods involve short-term incubation of soil under controlled temperature and moisture conditions. The amount of mineralized N is then related in an empirical manner to crop yields established in greenhouse and/or field plot studies. Another approach is to estimate the amount of potentially mineralized N which is present in soil during any given time period and to measure its rate of mineralization. Using this approach, it should be possible to estimate the amounts of N made available to plants during specific plant growth stages during the season, provided that available information on termperature and other environmental factors is used correctly. The main difficulty with all methods developed to estimate mineralizable N is that the rate and extent of mineralization are dependent upon climatic factors. Although knowledge of the mineralization potential of a soil gives a rational basis for estimating the amount of soil organic N likely to be released for plant growth, the actual amount that will be released cannot be predicted accurately unless the seasonal climatic pattern also can be predicted accurately.

Some of the fertilizer N not taken up by plants during the season of application may remain residual in soil as inorganic N. This may especially be true following a dry season where uptake of applied N may be considerably less than expected. Knowledge of the amount of residual inorganic N in the soil is the third piece of information needed for making a prescription for optimum use of fertilizer N. Soils which receive repeated heavy applications of N can accumulate considerable amounts of nitrate throughout the soil profile—amounts as high as 448 kg N/ha (400 lb N/acre) have been noted. The pattern of inorganic N distribution within the soil may be extremely erratic, thereby greatly decreasing the accuracy with which the potential supply of available N can be estimated early in the growing season. Nevertheless, usable average values can and should be obtained.

The fourth kind of information needed is an estimate of the percentage of applied N which is taken up by the crop during the season of fertilizer application. This value commonly will vary from 30% to 70%, and is determined by the kind of crop, management, supply of available soil N, and weather, among other factors. A recovery of 50% to 60% of the N applied is usual for corn and small grains, 70% for pasture, and 45% to 50% for flooded rice.

Accurately determining this value for a particular crop and fertilizer management system is not easily accomplished. Nontracer methods for estimating percentage recovery of applied N depend on measuring yield differences between fertilized and unfertilized experimental plots. Where no yield response is obtained for applied N, measuring the percentage uptake of soil versus fertilizer N is virtually impossible without use of N tracer techniques.

Interpretation of tracer data in this regard also may present problems, especially where appreciable immobilization and remineralization occurs during the growing season. Problems of estimating percentage recovery of applied N using either tracer or nontracer methods have recently been discussed by Hauck and Bremner (3), Hauck (1), and Tucker and Hauck (12). Standord (9) discussed percentage uptake of applied N as affected by N rate, time of N application, and level of soil N supply.

In determining the efficiency of N fertilizer use, one should be concerned not only with the uptake and use of the applied N, but also with its effects on plant uptake and use of the total N supply. During the year of application considerable fertilizer N is immobilized, some of it being remineralized during the growing season, and perhaps 20% to 45% remaining immobilized after the first year. Soil organic N also is mineralized and either absorbed by the plant, reimmobilized, or retained by the soil, transformed, and/or leached as inorganic N.

Nitrogen tracer studies can measure the effects of applied N on the uptake of soil N, and can measure also the extent of mixing of N from soil and fertilizer. They can be used to measure the rate of release and plant uptake of N which was immobilized in previous years (about 5% to 15% of immobilized N is mineralized the year following immobilization; about 2% to 5% of that immobilized may be mineralized annually thereafter).

However, present tracer techniques do not permit one to accurately measure the balance of the total soil N supply, as this supply is modified through fertilizer additions; that is, measuring residual labeled fertilizer in the soil gives no indication whether this residual N represents a gain of N by the soil, or whether the fertilizer N has replaced soil N which is subsequently taken up by the plant or lost from the soil.

Prospects for Improving Efficiency

Ideally, the amount of fertilizer N that should be applied would equal the amount taken up by the plant at its highest level of attainable yield and/or profit, plus the amount which is immobilized in the soil during the growth season. No residual inorganic N would be present after harvest, subject to loss via leaching or denitrification. From a practical viewpoint, highest profits occur only where N in excess of that taken up or immobilized is applied. A practical balanced viewpoint makes some compromise between maximum profit and zero tolerance for residual inorganic N.

Past N fertilizer recommendations have to some degree used the four basic kinds of information outlined in the preceding section. Rules of thumb based on crop requirement have been used for many years; e.g., add 1, 1.5, or 2 lb of N for each bushel of corn expected, depending on the yield level.

A more refined value for crop N requirement can be obtained by establishing field plot trails over several years to determine the internal N requirement at the maximum attainable yield for a particular locality and crop. Currently, crop N requirement and optimum yield levels usually are estimated on the basis of past experience. Where high levels of inorganic nitrogen may be present in soil, farmers may have their soils analyzed for residual mineral N and consider in their current fertilizer applications the fertilizer N that may not have been taken up by plants the preceding year because of drought or other yield-limiting climatic factors. Research still is needed to improve sampling methods for residual mineral N, especially where mineral N has accumulated in the subsurface horizons of soil.

The determination of residual mineral N with an adequate degree of accuracy is possible in a well managed farm operation. However, the assessment of mineralizable N and percentage recovery of applied N cannot easily be accomplished on a commercial farm. As previously mentioned, regardless of the degree of refinement, all methods developed to predict the amount of soil organic N likely to become available for plant growth during the growing season are limited by the difficulties of predicting the effects of seasonal factors on mineralization and plant use of N. It may only be possible to determine the maximum amount of mineralizable N in a soil and then, on the basis of known effects of seasonal factors on mineralization rate, to calculate the amount of N likely to be made available over an average season. Estimates of the expected percentage recovery of applied N can best be verified for different rates of N with field trials using N tracer techniques. In the absence of such trials, the farmer must assume an average value for "fertilizer efficiency" (defined in this instance as percentage uptake by plants of applied N) based on previous yield response data.

It is obvious that the more detailed and accurate the basic information on crop N requirement, plant uptake of N, soil N supply, and soil N transformations, the more accurate the prescription can be for maximizing the efficiency of fertilizer N use consistent with minimizing environmental stress. No commercial farm operation can afford the expense, time, and effort to obtain all of the information needed for optimizing N fertilizer use. However, intensive studies of typical crop management systems should produce information which can be used for refining fertilizer recommendations on farms for which only general information is available. This approach is used effectively to disseminate knowledge of soil-fertilizer reactions obtained under highly controlled experimental conditions.

For example, numerous studies show that urea is less effective as a source of N if surface applied than if incorporated into soil because of ammonia loss from the soil surface. However, because the microsite chemistry of the urea-soil reaction zone is well understood, one can be reasonably sure that little or no urea N will be lost if urea is added within a few hours of a drenching rain, a rain of sufficient intensity to obliterate the discrete urea-soil reaction zones. Information on the organic matter and clay contents, and urease activity of a soil will permit one to further identify fertilizer management practices which lead to improved use of urea and urea-based solutions.

Thus, the four kinds of basic information discussed above are necessary for determining how much N should be applied for maximum yield and minimum environmental stress. Economic information is used to relate maximum yield to maximum profit, consistent with envrionmental concerns. Knowledge of N fertilizer-soil reactions, as affected by N source and soil physical, chemical, and biochemical properties, is necessary to determine how to use the recommended amounts of fertilizer N in the most effective way. When one fails to use the information that is available or fails to develop information that is necessary, yield limitations occur or fertilizer N is wasted.

Conclusion

Economic constraints and increasing need for environmental concerns will encourage farmers to maximize the efficiency by which N fertilizers are used, where efficiency is defined in terms of crop yield and quality, profit, and minimal level of residual inorganic N in the soil after harvest. Eventually, the level of immobilized fertilizer N also may be included in the definition of efficiency. A yield level of about 85% to 90% of the maximum attainable yield appears to satisfy the criteria for a responsible viewpoint of N fertilizer efficiency. At this yield level, most of the recommended rate of fertilizer N is either taken up by the plant or immobilized in the soil. Aiming for 10% to 15% below the maximum attainable yield minimizes waste of fertilizer, shows concern for potential long-term adverse effects of intensive N fertilizer use, and provides some latitude for excessive fertilizer use during a below-average cropping season.

Not all farmers can or are willing to follow a prescription for optimum use of N according to the criteria set forth above. Labor management problems, the nonavailability of fertilizer, and adverse weather conditions are among the factors which inadvertently lead to suboptimum use of N. Desire for maximum profit may lead to inefficient N fertilizer use. Even under ideal operating conditions and with the most responsible of attitudes, a prescription for optimum use of fertilizer N may fall short of this objective. Nevertheless, an already substantial pool of knowledge of N fertilizer use is available. Additional information directed toward increasing N use efficiency in specific crop management systems is continually being developed. The task is to tailor this information to individual crop farm operations.

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Life After Frost

Some plants can survive freezing temperatures, but the hows and whys of cold-hardiness are still largely unknown

By Anne Moffat

All gardeners know the disappointment of frost injury. An early autumn frost or a late spring frost transforms a vigorous plant into a limp, dark, moist mass of dead tissue.

Fear of frost injury has haunted man since he first cultivated plants. On several occasions the damage brought on by insufficient cold-hardiness has altered the course of history. For example, the year 1816 is important to students of American history as a year of peak migration from the New England colonial centers to the unsettled upstate and western regions of New York. That year, now known as "eighteen-hundred-and-froze-to-deat" in Vermont, was marked by snow in June, frost in July, and dramatic frost damage to crops throughout northern New England.

Today, scientists studying the relative cold-hardiness of plants are concerned that climate may cause more damage to crops in some areas than all parasitic diseases, and that sensitivity to frost is the single most important factor inhibiting plant distribution and agricultural production in temperate regions. It is well known that cereal crops which over winter, such as wheat, oats, and rye, have 20 percent greater yield than those species planted in the spring and harvested later in the summer. If the factors that distinguish these plants' cold-hardiness could be better understood, progress could be made in reducing the 10,000 daily deaths attributable to malnutrition.

There are many types of injury resulting from winter conditions which are collectively referred to as "winter injury" or "winter kill." These include mechanical damage to shade tree bark by frost, winter desiccation of broadleaved evergreens such as holly, kalmia, leucothoe, and rhododendron species, and frost heaving of cultivated plants. Although all of these winter injury problems must be considered in the cultivation of a species, they are not cold-hardiness problems in the true sense. To a plant scientist the phrase "cold-hardiness" has a special meaning. It refers to a plant's ability to survive an unfavorable environmental temperature.

Why some plants survive freezing temperatures has long been controversial, and botanists have published observations on the subject since the early 17th century. Until fairly recently it was thought that plant tissues expand on freezing and ultimately rupture. The limpness of thawed herbaceous plants was believed to be due to cell rupture. Because water expands when it freezes, and because plant cells are mainly water, it seemed sensible to assume that the damage done to living cells is similar to the damage done to a closed, water-filled jar that is frozen. It bursts, shattering into thousands of useless fragments.

This logical assumption is wrong when applied to plants. Most plant cells actually shrink when frozen. This is what happens: Water generally freezes at 32 degrees F., but very purse water can be supercooled to minus 40 degrees F. before it begins to form ice. This is because the initiation of ice formation requires seeding by impurities, called nucleators.

In plants, most water is normally contained within individual cells. But because the cell wall is believed to be a better nucleator than anything inside the cell and because the cell membrance acts as a barrier against the introduction of ice, ice crystals first form outside and between the individual cells and, as water continues to diffuse out of the cell, the volume of material inside the cell decreases and the cell eventually shrinks. The remaining protoplasm contracts around the nucleus. And as the solute concentration within the cell increases, the cell's resistance to freezing increases.

Ice formation takes place within cells only if the temperature drops too quickly for water to leave the cells, a very rare occurrence in nature.

It is the removal of water from a plant cell that takes the most severe toll, and not a puncturing, tearing or bursting of the cell structure. The dehydration that accompanies freezing has a number of stressful consequences for the cell. Removal of water increases the concentration of solutes, decreases the volume of the cell, alters the interactions between biologically important large molecules, causes the precipitation of some salts, and alters the acid-base balance of the cell. The ultimate injury is to the fragile cell membrane, which separates the cell's contents from the sturdy spongelike cell wall. If the membrane loses its integrity and its ability to regulate the flow of water and other substances into the cell, the life support system collapses. The measurement of a plant's hardiness is an evaluation of a cell's ability to survive these stresses.

The obvious approach to the study of cold-hardiness is to define what distinguishes those plants that survive low temperatures. Plants that are hardy exhibit two distinct qualities: They have a genetic capacity to withstand low temperatures, and they have the proper conditioning for expression of

the heritable quality.

This inherent trait of hardiness is easy to understand and immediately one can cite genetic examples at both ends of the scale. Very cold-sensitive species include aracia, citrus, and eucalyptus; some cold-tolerant species are birch, spruce, and poplar.

The second types of hardiness is more subtle and requires that the plant receive certain environmental cues to become fully hardened. This is the basis for the annual cycle of cold-hardiness that plants exhibit. In winter many plants are able to withstand freezing temperatures of minus 50 degrees F., but in summer they are as susceptible to freezing temperatures as are citrus species. Conifers fall into this category. English ivy can also survive minus 30 degrees F. in the winter, but in the summer, without the appropriate hardening process, it is killed by temperatures of 25 degrees F.

Plants that lack the genetic capacity to withstand low temperatures are considered unhardy or frost-sensitive. Plants that have the genetic capacity but have not experienced the correct environmental cues for its expression are said to be in an unhardy condition. Plants that have the genetic capacity and have received the proper environmental cues are considered to be in a hardy condition.

Of the many factors that influence the cold acclimation process, day length seems to be as important as low temperature. In woody plants it is believed that there are three phases in the hardening process. During the first phase, which is triggered by shorter day lengths, growth ceases and terminal buds are intiated. With deciduous trees this phase is marked by the onset of autumn coloration and is completed with the loss of leaves. The second phase commences when the temperature descends to 32 to 40 degrees F. At this temperature, plants with the genetic capacity for cold acclimation show large increases in hardening. During this phase deciduous trees don't require light, but the broad-leaved and coniferous evergreens still depend on diminishing daylight as a cue to the onset of frost-hardiness. The third phase, which is the least well understood, is triggered by freezing temperatures.

A lesson to be learned from an understanding of the discrete phases of cold acclimation is that a plant should not be coaxed into continuing its summer growth, via late fertilizattion or other techniques, beyond the normal period. To do so will only cause it to miss important autumn cues to the hardening process. And gardeners should also be cautioned against prematurely building elaborate over-wintering structures. Such "protection" from dropping temperatures will also deprive the plant of needed environmental cues and render it vulnerable to hard frosts. High temperatures in the fall effectively decrease hardiness, too.

Many of the recent advances in cold acclimation studies have come from artificial induction of cold-hardiness, followed by controlled freezing conditions and determination of plant survival. The standard procedure for artificial cold acclimation is to hold plants at 40 degrees F. for six weeks with an eight-hour photoperiod at an intensity of 600 ft-candles. Under these conditions plants increase in hardiness at rates similar to those exposed to natural conditions. This period is critical for studies of the mysteries of cold acclimation and how hardy plants survive freezing.

Unfortunately, it is at this point in the study of cold-hardiness that those with an amateur interest in the subject become frustrated, confused, and disappointed. And they discover that scientists working in the field seem to be distinguished by discord. Even though the latter generally agree that cell membranes are sites of critical injury, they vigorously disagree about what goes on during the hardening process and what eventually causes cells to succumb to the cold.

Dozens of biochemical changes, such as increases in sugars, soluble proteins, and fatty substances, have been correlated with the onset of hardiness. But it remains to be determined which of these changes are causally related to the cold acclimation and which are coincidental.

Most scientists do agree on one further point—that in both hardy and unhardy plants ice crystals are formed and the cells are subjected to the repercussions of the freezing process. But it's unknown why some tissue survives and other tissue does not.

Here are some of the ideas offered to explain the development of cold-hardiness in plants.

Many researchers have recorded a decrease in starch content in plants building up hardiness and an accompanying increase in sugar concentration. Sugar appears to be an important antidote to freezing, but not because it acts as an antifreeze. It is believe that sugars may reduce the build-up in salt concentration that always accompanies cell freezing and dehydration, or they may render the cell membrane more resistant to increased salt concentration. Another theory holds that sugars form sugar/protein complexes, thus stabilizing the proteins. But theories supporting sugar as a cyroprotectant are not without flaws. Indeed, sugar cane has a high concentration of sugar yet is very frost-sensitive.

Another favorite theory is that hardy cells have a high permeability to water, permitting all readily freezable material to leave the cell and allowing the cell to supercool. Related to this idea is the concept of vitrification or gelling. Such gelling would be promoted by the aggregation and cohesion of protein molecules, which traps the remaining liquid phase of protoplasm in a three-dimensional network of a solid phase. This might protect the cell against mechanical deformation, dehydration, and formation of intracellular ice by reducing the mobility of the water molecules. Also, gelling may reduce the biochemical activity of the protoplasm and the harmful effects of concentrated solutes.

Still other researchers have suggested that cold-hardiness is affected by an increase in soluble proteins and ribonucleic acids (RNA), and in oil and fat concentrations.

No one knows exactly what biochemical event or series of events endows a plant cell with resistance to frost. And because there is no clear description of what triggers cold-hardiness, any efforts to design a synthetic cryoprotectant have been stymied.

Yet, despite the frustrations associated with cold-hardiness research, there is a special lure that keeps scientists curious. That interest is fueled by more than the knowledge of the practical benefits, such as increased agricultural production and prolonged flowering of annuals, that would accrue with an understanding of cold-hardiness. It involves the intellectual excitement of discovering why plants have the ability to endure freezing temperatures.

Simply stated, many plants have succeeded in developing defenses against freezing stresses that most animal cells haven't developed. That mystery is waiting to be solved.

PROTECTING PLANTS

A home gardener's best protection against problems of insufficient cold-hardiness and other winter injuries is careful selection of plants, followed by good horticultural care. Follow-up care should involve timely fertilization. If excessive levels of nutrients are provided to plants so that fall growth is promoted, cold temperature injury could occur because the late growth would not have ample time to develop cold-hardiness. Attention should also be paid to satisfactory drainage, moisture, salts and nutrients. An imbalance of any of these can reduce a plant's cold-hardiness.

However, even with strict attention to these matters, gardeners still encounter frost injury, especially with marginally hardy species. Although there is no known universal panacea for frost injruy, horticulturists and landscape architects have perfected some techniques for providing insurance against such injuries. Most involve cultural tricks or, simply, awareness of the climate variations or "microclimates" within a garden.

Many of the most common plant injuries incurred in the colder months are not related to cold-hardiness but involve damage due to desiccation, the cracking of tree bark, and snow loading.

Problems of desiccation, or drying out, are caused when plants, firmly rooted in frozen soils, get a good, long dose of brilliant winter sun. The leaves begin to transpire, lose water, and are unable to replace the lost moisture because the ground is frozen. Broad-leaved evergreens and some narrow-leaved evergreens are vulnerable to this problem. Prevention calls for wise planting strategies including mulching to reduce frost penetration into the soil, and shading plants from harsh winter glare and winds.

Another common winter injury is snow loading, which causes crushing and breaking of stems and branches. Deciduous birch, rhododendron and azaleas are often affected by this malady. If you live in an area where late, wet snowfalls or excessively heavy snows are anticipated, wrap valued plants in loose, tent-like structures that shed snow.

Cold, sunny winter weather can also cause the bark of some smaller trees to crack, often with a sound resembling gunshot. These trees can be protected by wrapping them with a paper-like tree wrap, burlap or cheesecloth.

Avoiding problems related to insufficient cold-hardiness is more difficult, but certain precautions can reduce their frequency. Because young roots are especially vulnerable to cold injury, and because air is a poorer insulator than earth, plants in containers are more susceptible to freezing injury than are those in soil. Unless you have exceptionally hardy plants, it is best to provide outdoor potted plants with additional protection.

Cold injury can also be avoided by studying the microclimates within a garden and, perhaps, manipulating them. For example, orchardists are well aware that cold air sinks and that the blossoms of fruit trees are extremely vulnerable to spring frosts. Therefore, they avoid planting in valleys. Several researchers studying the temperature gradations in a Pennsylvania valley found a consistent increase in the air temperature of about 6.2 degrees C. for each 100 meter of elevation above the bottom of a basin confining cold air. Obviously, gardeners should study air circulation and give special attention to the site selection for plants with questionable cold-hardiness.

Much frost injury is also attributable to radiation frosts. These occur in early fall or late spring, on clear nights because of the absence of clouds that would otherwise trap warm air close to the earth. Nights of radiation frosts are generally preceded by clear days during which the soil receives some heat from the sun. When frost-threatened plants are small enough, it is possible to protect them from isolated radiation frosts by covering them with some type of material. These covers, termed hot caps, are placed over small plants in the late afternoon and removed the next morning.

If, despite all protective strategies, you plants are plagued by frost injury, don't be too anxious to prune. Often, the leaves may die, but the stem remains vigorous. Wait until spring to be sure there is no life, then prune the dead portions.

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Liability and The Lawn Care Industry

Author discusses the many facets of potential for liability in the lawn care industry and how to avoid violations and losses

By Dr. Roger Funk

The lawn care industry may be subject to a number of possible liabilities because of high visibility in residential areas and the application of fertilizer and pesticides to turfgrass in proximity to ornamentals and accessibility to children and pets. Warehousing, handling and transportation of chemicals and disposal of chemical wastes may also create potentially hazardous situations.

The use of pesticides is not new. As far back as 70 A.D., Plinius recommended arsenic as an insecticide and the Chinese regularly used arsenic sulfide during the late 16th century. However, it was not until after World War II that large quantities of pesticides were used to support the dramatic growth in agriculture.

During the late 1950's and early 1960s reports of pesticidal buildup in the soil created an atmosphere of uncertainty over long-term environmental and human safety. Rachel Carson's book, *Silent Spring,* published in 1962, focused much more attention on the potential hazards from the use of pesticides and, although much of her book was based on speculation and supposition, it undoubtedly helped to increase awareness of the need for more research.

In more recent years, sustained efforts have been made by well-meaning but misinformed environmentalists and other pressure groups to drastically reduce or eliminate the use of pesticides. Those individuals usually represent a vocal minority with a naive wish for a totally unrealistic, zero-risk approach to all phases of human activity—an approach that is neither practical nor desirable in the real world where we must live and work. Tactics have included public hearings, political pressure, court action and adverse publicity in newspapers and on radio and television. The news media are particularly useful in swaying public opinion since vivid anecdotes and dramatic testimonials are more persuasive and memorable than dry, statistical fact.

Producers and users of pesticides have traditionally avoided public discussions of pesticides out of a fear of introducing a seed of doubt where none existed. The unofficial policy has been to "let sleeping dogs lie." However, as opposition groups have become more organized and vocal, we've had no alternative but to take the offensive and knowledgeably discuss the issues at every opportunity.

Informed individuals can participate on a local basis by writing newspaper articles and by presenting industry views at civic and garden clubs. Lawn care organizations such as the Professional Lawn Care Association of America (PLCCA) can represent the industry at governmental hearings and act as consultants in the development and implementation of laws regulating pesticidal use in urban areas.

FIFRA

In 1947, Congress passed the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) that requires, among other provisions, the federal registration of all pesticides by the United States Department of Agriculture and adequate labeling of all containers. However, it wasn't until the Federal Environmental Pest Control Act (now known as Amended FIFRA) was passed in 1972 that a method was established to penalize violators of label directions. For commercial violators, a civil action penalty can be a fine of up to $5,000. For a convicted criminal violator, the penalty can be a fine of up to $25,000 and a one-year jail term for the use of pesticides inconsistent with their label directions.

Unfortunately, label directions are not always clear and are subject to interpretation by Environmental Protection Agency (EPA) compliance officers. For example, practically all pesticidal labels carry a statement indicating that the pesticide should not be applied when weather conditions favor drift from treated areas. Since the lawn care industry is relatively new and a relatively small user of pesticides these conditions are not always known to either the manufacturer or the EPA. In addition, since liquid lawn application techniques vary significantly in regard to height and angle of spray, particle size and spray viscosity, the drift potential is not standard for all companies. Yet you could be cited for a violation if a compliance officer felt that your firm had violated the drift requirement of a label.

The elimimation of drift is a major objective of the EPA and will be receiving much more attention in the near future. The term "chemical trespass" refers to involuntary exposure to pesticides and the right of a person *not* to be exposed to pesticides if he or she does not wish to be. This would also include chemical odors.

Hazardous Wastes

Another major EPA project is the regulation of hazardous wastes. In 1980, the EPA Hazardous Waste Management System was promulgated under the authority of the Resource Conservation and Recovery Act (RCRA) and regulates the generation, transportation, treatment and disposal of hazardous wastes. A waste is considered hazardous if it is ignitable, corrosive, reactive or toxic and may cause serious illness, increased mortality or a substantial hazard to the environment when improperly managed. Generators of hazardous wastes must comply with regulations on record keeping, labeling, containers, furnishing information to transporters, a manifest system and reporting to the EPA or to a designated state agency.

The EPA has acknowledged that lawn care firms are not generators of hazardous wastes during the course of normal operations *when* proper procedures are followed in disposing of empty pesticidal containers, cleaning spray tanks and washing spray trucks.

Under no circumstances should a professional lawn service be vulnerable to being labeled as a hazardous waste generator, unless there is an accidental spill. Those who are apt to be cited as hazardous waste generators are those who accumulate large quantities of pesticidal containers, dump unused quantities of mixed spray materials, wash filthy spray trucks allowing water to run into storm drains or ground water, store pesticides that have been banned, allow tank mixes to slop out of hatch covers, allow spray units to leak or permit any other such practices. Worse yet, these are the violators who can damage the image of the entire industry.

If an accidental spill occurs that generates non-exempt quantities of hazardous wastes, obtain an emergency EPA identification number (if your company has not already applied for and been granted a number) before attempting to transport or dispose of the wastes. A chemical spill that pollutes ground water may be subject to a fine of $10,000 per day per occurrence. If the pollution was intentional, the penalty could be as much as $25,000 or a jail sentence or both.

Emergency help can be obtained by contacting the Pesticide Safety Team Network (PSTN), a cooperative volunteer program operated as a public service by the National Agricultural Chemicals Association (NACA) and participating companies. A list of area coordinators is available from the NACA, 1155 Fifteenth Street, NW, Washington D.C. 20005. The 24-hour toll free phone number of the PSTN Telephone Central (CHEMTREC) is 800/424-9300.

Fire Precaution

Information concerning the potentially hazardous nature of pesticides and fertilizers in case of fire is usually available from manufacturers. Trade organizations may again be helpful by accumulating this information and disseminating it to member companies.

Most pesticides decompose in the heat of a fire and can release toxic gases, vapors and smoke. With some products you may see toxic gases escaping, but often the gases are colorless. Fertilizers, too, can release toxic gases when burning. Ammonium nitrate-containing fertilizers decompose and release very toxic oxides of nitrogen, one of which, nitrous oxide, is an oxidizer and increases the burning rate of the fire.

Fertilizer grade ammonium nitrate is less concentrated than the grade used for explosives and is not normally considered an explosion hazard. The explosion hazard is increased, however, by contamination with organic material such as oil, sulphur, grease and charcoal, and combustible dusts. Fertilizers containing more than 15 percent ammonium nitrate should be safeguarded with special storage arrangement. Other fertilizers are not explosion hazards or oxidizers but they may decompose at very high temperatures and release toxic gases.

New York State now requires fire insurance policy holders who have had hazardous materials at any permanent place of business within the past year to fill out Hazardous Material Reports annually on or before the anniversary dates of their policies and submit them to local fire chiefs. This information will help fire departments determine what precautions and special equipment are necessary in fighting warehouse fires.

Insurance

Lawn care companies, particularly those with less than five hundred thousand dollars in gross annual sales, are finding it increasingly difficult to obtain insurance because of the growing concern surrounding the use and disposal of pesticides. The problem is compounded by the lack of understanding of our industry by insurance companies. One lawn company's policy was cancelled because the insurance carrier interpreted the spraying of lawns with pesticides as "intentional pollution." Because of similar difficulty in the structural pest control industry, the National Pest Control Association is sponsoring general liability insurance for member companies. The result has been standardized coverage, lower premiums and better loss control by member companies.

“Most, if not all, companies are providing written notices to clients to keep children and pets off the lawn until the spray application dries.

Although insurance requirements vary, most states require, as a minimum, general liability and property damage. Some states also require Security Bonding in the amount of $20,000 to $50,000. Unfortunately, some lawn care companies have found that their policies do not cover pesticidal spraying or that the coverage was vague and subject to interpretation. In fact, the standard general liability policy excludes pesticidal spraying unless there are special endorsements waiving this exclusion.

In addition, general liability insurance is often separated into two elements: sudden and occurrence. Occurrence refers to contamination that unknowingly occurs over a long period of time and is often excluded in policy coverage.

Other "gaps" that often occur in coverage and should be considered are vandalism on the lawn, unauthorized usage of company equipment and misapplication through negligence or malfunction of equipment.

If you are unsure of your coverage, contact your current insurance carrier and have the coverage broadened, if necessary. It should

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be noted that no insurance policy will cover the use of a pesticide prohibited by law or where the application violates any law, ordinance or regulation. Insurance companies also normally consider only those lawn care firms with good safety records.

Included in a draft prepared by the EPA's Office of Pesticide Programs, which proposed 1981 to 1985 strategy, was a suggestion for mandatory personal liability insurance for applicators. It proposed

Table 1

12 Steps to Hazard and Liability Reduction

1) Read pesticide labeling and follow directions.
2) Obtain safety data sheets from manufacturers for all materials used.
3) Notify local fire department of any hazardous materials stored in your facility.
4) Know your state and federal hazardous waste regulations.
5) Make chemical handling, storage and usage part of job safety analysis and of the work procedures used by your employees.
6) Recover and recycle wash water.
7) Prepare a spill prevention, control and countermeasures plan to keep spills of hazardous materials from becoming pollutants.
8) Maintain good housekeeping in warehouses to minimize accidents, health and fire hazards.
9) Train applicators in proper application procedures to confine spray to target area.
10) Provide driver safety training, including safety checks for equipment.
11) Keep current through trade magazines, newspapers, seminars and trade associations.
12) Handle complaints promptly and courteously.

minimun coverage of $100,000 per victim and $500,000 per day of spraying. It stated that the insurance would more adequately compensate "victims," lead to a direct reduction in misuse due to economic incentive and add to the cost of toxic chemical application that would lead indirectly to further reductions in overuse and misuse.

Serving Notice

Major liabilities may arise because of "failure to warn" on the part of the lawn care company. Most, if not all, companies are providing written notices to clients to keep children and pets off the lawn until the spray application dries. Some companies are also providing a list of the chemicals included in each application and have labels and technical data available upon request.

Most situations that could lead to liability can be minimized through proper education of employees (Table 1). Compliance officers within governmental regulatory departments stress the need for technical services and employee education to apply registered pesticides safely. Training applicators is viewed as a more effective problem-solving approach to pesticide regulation and hazard reduction than is strict enforcement.

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